2019

MINIMIZING BEE BYCATCH IN JAPANESE BEETLE TRAPS

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BY

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A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE

REQUIREMENTS FOR THE DEGREE OF

MASTER OF SCIENCE

IN

BIOLOGICAL AND ENVIRONMENTAL SCIENCES

UNIVERSITY OF RHODE ISLAND

2019

MASTER OF SCIENCE THESIS

OF

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2019

ABSTRACT

Native and introduced bees were attracted to and captured in commercially available Japanese beetle, *Popillia japonica* Newman, traps baited with floral lure components (geraniol, eugenol, phenethyl propionate [3:7:3]). Studies in Rhode Island found that *Bombus impatiens* Cresson was significantly more attracted to geraniol alone and as a component in a floral lure blend than to either eugenol or phenethyl propionate alone. *Xylocopa virginica* L. was more selective in being primarily attracted to traps baited with higher amounts of geraniol in 2016. In 2016, 32 baited and eight unbaited traps captured 856 *B. impatiens* and 124 *X. virginica* in 11 days of trapping in Rhode Island. In 2017, a total of 3,749 bees were captured in 124 traps in Rhode Island over 56 days and 90 in 32 traps in Ohio over 42 days. Removing geraniol from the floral lure reduced the bee capture but did not significantly reduce the Japanese beetle capture in 2017 and 2018. In 2018, a total of 708 bees were captured in 100 traps in Rhode Island over 56 days, 401 bees were captured in 68 traps in Tennessee over 60 days, and 34 bees were captured in 32 traps in Ohio over 58 days. Removing geraniol from Trécé dual lures significantly reduced bee captures in Rhode Island in 2018. Green, black, brown, and red traps captured significantly fewer bees than clear or standard yellow vane and green cage traps in 2018 in Rhode Island and Tennessee. The results suggest that using all green traps with a lure composed of eugenol and phenethyl propionate and the Japanese beetle male sex pheromone can effectively capture Japanese beetles while minimizing the bycatch of bees.

ACKNOWLEDGMENTS

I thank my major professor Dr. Steven Alm for all his assistance, guidance, and support. I also thank all my collaborators for their cooperation and assistance. Finally, I thank my friends and family for providing me with invaluable support every step of the way. Without all of these people, none of this would have been possible.

PREFACE

This thesis “Minimizing Bee Bycatch in Japanese Beetle Traps” is being submitted in manuscript format. This thesis will be submitted for publication to an academic journal.

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This manuscript “Minimizing Bee Bycatch in Japanese Beetle Traps” is prepared for submission to the journal Environmental Entomology.

INTRODUCTION

Traps used to monitor Japanese beetles**,** *Popillia japonica* Newman (Coleoptera: Scarabaeidae), are known to also capture nontarget organisms, including bees (Hamilton et al. 1970). The Japanese beetle is an introduced pest that feeds on over 300 species of plants (Vittum et al. 1999). The U.S. Department of Agriculture Animal and Plant Health Inspection Service (APHIS) maintains the federal Japanese beetle quarantine and regulations (USDA, APHIS 2016). The objective of the Japanese beetle quarantine is to protect agriculture in western states and prevent human assisted spread of the beetle from the eastern U.S. The states protected by the Japanese beetle quarantine are: Arizona, California, Colorado, Idaho, Montana, Nevada, Oregon, Utah, and Washington (National Plant Board 2016). In California, trapping for adult Japanese beetles has been conducted for many years. Over 12,000 traps are deployed and monitored during the Japanese beetle flight season (CDFA 2016). In 2007 and 2008, Utah deployed approximately 3,250 Japanese beetle traps as part of the Utah Department of Agriculture and Food (UDAF) Japanese beetle monitoring and eradication program (Strange et al. 2011). In 2016, Oregon Department of Agriculture's Insect Pest Prevention and Management Program placed 2,620 Japanese beetle traps (fewer than normal due to budget constraints) and captured 369 beetles, the highest number captured in the program's 72-year history (Oregon Department of Agriculture 2016). California, Colorado, Oregon and Utah have conducted several successful Japanese beetle eradication programs since 1961 (CDFA 2014, ODA 2016). Traps are used in delimitation surveys by state regulatory agencies after accidental introductions, and in some cases, to certify nurseries as Japanese beetle free. (National Plant Board, 2016). Landscape managers and homeowners also use traps to monitor and/or control Japanese beetles.

Several companies produce lures and traps to monitor and control Japanese beetles. It has been known for some time that Japanese beetle traps and lures will attract and kill bees (Hamilton et al. 1970, 1971; Ladd et al. 1974). In a Japanese beetle trap study with various lures on Nantucket Island, MA, Hamilton et al. (1970) captured 22,885, 6,545, and 1,957 bumble bees (*Bombus* spp.) in 2,332, 2,750, and 2,650 traps during 1965, 1966, and 1967, respectively. While trapping Japanese beetles for another experiment we were conducting in 2016, bee captures were noticed in the traps. Given the increased interest in conserving both native bees and introduced bees, it is worth revisiting the impact Japanese beetle traps may be having on bees.

Our objectives were to: 1) evaluate the attractiveness of the Japanese beetle floral lure blend (geraniol, eugenol, and phenethyl propionate) and each of these components at different amounts to determine which were most attractive to bees, and 2) evaluate lure components and trap colors and designs to determine which would reduce bee captures yet still capture Japanese beetles.

MATERIALS AND METHODS

Experimental designs. A randomized complete block design was used either in a grid or line arrangement of traps at 10 m spacing. Traps were suspended on poles with funnel rim heights at 1 m. Traps and lures were tested in mowed and unmowed areas at horticultural research farms as well as along a tree and brushy border adjacent to a mowed eight ha athletic field complex in Kingston, RI. Traps and lures were tested at a horticultural research farm in Wooster, OH, and the forested edge of a field-grown nursery in McMinnville, TN. We analyzed the mean $\pm$ SEM total bee taxa and Japanese beetle captures for each treatment for the entire trapping period for each experiment. Trap captures were collected and frozen three times per week in Rhode Island in 2017 and 2018, two to three times per week in Tennessee in 2018, and three to five times per week in Ohio in 2017 and one to two times per week in Ohio in 2018. Japanese beetles were counted by weighing 20 males and 20 females and extrapolating the weight in Rhode Island and Tennessee and volumetrically in Ohio. Bees were sorted to family, genus, or species level and counts recorded in 2016, 2017, and 2018. Traps were rerandomized daily in 2016 and on each collection date in 2017 and 2018.

Attractiveness to Lures and Lure Components

Attraction of Bees to Individual Floral Lure Components and the Three Component Blend at a Rhode Island Mowed Site, 2016. After initial observations of bee captures in Japanese beetle traps, lure components (geraniol 98%, eugenol 99%, and phenethyl propionate 98% [PEP]; Sigma Aldrich, St. Louis, MO) and the three component blend were evaluated for bee attraction. There were four replicates of five treatments: 1) 3 ml geraniol, 2) 3 ml eugenol, 3) 3 ml phenethyl propionate, 4) blend of 1 ml each of geraniol, eugenol, and phenethyl propionate, 5) control. Lures were placed on 5 ml pads (Gen Polymeric Corp, Reading, PA) in 15 ml polycon dispensers

(Madan Plastics Inc., Cranford, NJ) (the lure delivery system). Controls consisted of empty polycon dispensers and pads. Lures were inserted to the yellow tops of Trécé PHEROCON Japanese beetle standard traps (Fig. 1, Trécé, Adair, OK). We replaced the green collection cages with 473 ml glass jars to allow us to see when bees were captured and release them unharmed. The experiment in a mowed area was set up on 5 August 2016 and checked at 0930, 1230, and 1530 h daily to minimize the time bees were captured. The experiment ended 19 August 2016. Lures were replaced on 9 and 15 August 2016 to keep potency high in these preliminary experiments. Each time the traps were checked, the bees were identified and counted. The two primary bee species that were attracted to the lures were *Bombus impatiens* Cresson and *Xylocopa virginica* L. Because these species could be easily identified to species in the field, captures of these species became the focus in 2016. Captured bees were released 100 m from the study site. Trap collection jars were removed each day after the last collection to prevent traps from collecting bees in the evening.

Attraction of Bees to Individual Floral Lure Components and the Three Component Blend at a Rhode Island Unmowed Site, 2016. Four replicates of five treatments similar to the amounts used in Trécé Japanese beetle floral lure (3:7:3) (Ladd et al. 1981) were tested: 1) 0.7 ml geraniol, 2) 1.6 ml eugenol, 3) 0.7 ml phenethyl propionate, 4) 3 ml in a ratio (0.7 geraniol:1.6 eugenol:0.7 phenethyl propionate), and 5) control. All lure components were released from 5 ml pads in 15 ml polycons. The experiment was conducted from 11 - 19 August 2016 in an unmowed old field site with more floral resources than the mowed site. Traps (same type as at the mowed site) were checked daily at 0900, 1100, 1300, 1500 h to compensate for higher bee captures and to release them unharmed after a shorter period of capture than at the mowed site. Each time the traps were checked, the bees were identified and counted. Captured bees were released 100 m from the study site. Trap collection jars were removed each day after the last collection to prevent traps from collecting bees in the evening.

Attraction of Bees and Japanese Beetles to Commercially Prepared Lure Components, Rhode Island and Ohio 2017. Four replicates of eight lure treatments were prepared by Trécé: 1) 0.76 ml geraniol, 2) 1.78 ml eugenol, 3) 0.76 ml PEP, 4) 1.78 ml eugenol + 0.76 ml PEP, 5) three-component blend in the ratio 0.76 ml geraniol/1.78 ml eugenol/0.76 ml PEP, 6) pheromone [(R,Z)-5-(1-Decenyl) dihydro-2(3H) furanone] alone, 7) three-component blend in the ratio 0.76 ml geraniol/1.78 ml eugenol/0.76 ml PEP + 1 mg pheromone on rubber septa (dual lure), 8) control (blank Trécé commercial pads and rubber septa) and deployed in PHEROCON Japanese beetle standard traps (yellow top and green cage) (Fig. 2). Traps were placed along one side of a 10 m wide hedgerow between two athletic fields in Kingston, RI on 29 June 2017 and spaced 10 m apart. Lures were changed on 27 July (28 d) and trapping continued until 24 August 2017 (56 d total). The same treatments and replications in a grid design with traps 10 m apart were deployed in Wooster, OH on 5 July and continued until 15 August 2017 (41 d total). Lures were changed on 31 July 2017 (26 d).

Attraction of Bees to Individual Floral Lure Components and the Three Component Blend in Varying Amounts in Rhode Island Mowed and Unmowed Sites, 2017. Four replicates of eight treatments: 1) 3 ml geraniol, 2) 3 ml eugenol, 3) 3 ml PEP, 4) geraniol:eugenol:PEP in a ratio of 0.7 ml/1.6 ml/0.7 ml (the first four treatments were released from 5 ml pads in 15 ml polycons), 5) 0.76 ml geraniol, 6) geraniol:eugenol:PEP in a ratio of 0.76 ml/1.78 ml/0.76 ml, 7) geraniol:eugenol:PEP in a ratio of 0.76 ml/1.78 ml/0.76 ml + 1 mg pheromone (treatments 5 – 7 were released from Trécé's commercial pads and pheromone from rubber septa), and 8) control (blank Trécé commercial pads and rubber septa) were tested. Traps were set out in PHEROCON Japanese beetle yellow trap tops with 473 ml glass collection cage bottoms on 28 July 2017 and trapping continued until 18 August 2017 (21 d total). This experiment was repeated at an unmowed site with more floral resources on the same dates.

Attraction of Bees and Japanese Beetles to Commercially Prepared Dual Lures With and Without Geraniol, Rhode Island, Tennessee, and Ohio 2018. Eight replicates of four treatments: 1) standard Trécé PHEROCON Japanese beetle yellow trap top and green cage with Trécé dual lure, 2) standard Trécé PHEROCON Japanese beetle yellow trap top and green cage with Trécé dual lure without geraniol, 3) Trécé PHEROCON Japanese beetle green trap top and green cage with Trécé dual lure, 4) Trécé PHEROCON Japanese beetle green trap top and green cage with Trécé dual lure without geraniol were tested. Traps were set out on 29 June, 18 June, and 9 July 2018 and trapping continued until 24 August, 17 August, 4 September 2018 in Rhode Island, Tennessee, and Ohio, respectively (56, 60, and 58 d).

Attraction of Bees and Japanese Beetles to Trécé Japanese Beetle Pheromone Lures, Rhode Island 2018. Eight replicates of four treatments: 1) standard Trécé PHEROCON Japanese beetle yellow trap top and green cage (Fig. 3) with Trécé pheromone lure, 2) standard Trécé PHEROCON Japanese beetle yellow trap top and green cage with no lure, 3) Trécé PHEROCON Japanese beetle green trap top and green cage with Trécé pheromone lure, 4) Trécé PHEROCON Japanese beetle green trap top and green cage with no lure were tested. Traps were set out on 29 June and trapping continued until 24 August 2018 (56 d).

Attractiveness of Different Trap Colors and Designs

Evaluation of Trap Colors and Shields to Reduce Bee Captures at a Rhode Island Mowed Site, 2017. Four replicates of six trap color and shield configurations baited with the dual lure were compared: 1) PHEROCON Japanese beetle standard yellow top and green cage trap with no shield, 2) PHEROCON Japanese beetle standard yellow top and green cage trap + clear acetate shield (Fig. 4), 3) PHEROCON Japanese beetle green top and green cage traps with no shield and 4) PHEROCON Japanese beetle green top and green cage traps + clear acetate shield, 5) clear 3.2 mm plexiglass traps with translucent funnels (Fisher Scientific, Hampton, NH) (top) and clear 946 ml plastic cages (US Plastics, Lima, OH) (Fig. 5) no shield and 6) clear plexiglass trap + clear acetate shield were set out in a grid pattern 10 m apart on 3 July 2017 in Kingston, RI at a mowed site. Trapping ended on 26 July 2017 (23 d total).

Evaluation of Trap Color and Design (Translucent Funnel) to Reduce Bee Captures at a Rhode Island Unmowed Site, 2017. Four replicates of seven treatments: 1) yellow bee vane and no lure (Model ZYVT, SpringStar Inc., Woodinville, WA) (Fig. 6), 2) PHEROCON Japanese beetle standard trap (yellow top and green cage) with and 3) without Trécé dual lure, 4) PHEROCON Japanese beetle trap (green top and green cage) with and 5) without Trécé dual lures, 6) clear 3.2 mm plexiglass traps with translucent funnels (Fisher Scientific, Hampton, NH) (top) and clear 946 ml plastic cages (US Plastics, Lima, OH) (cage) with and 7) without Trécé dual lure were set up on 4 July and continued until 15 July 2017 (11 d total).

Evaluation of Trap Color and Design (Glass Funnel) to Reduce Bee Captures at a Rhode Island Unmowed Site, 2017. In the previous experiment it was noticed that the translucent funnels appeared white, especially when there was dew on the traps. Therefore, the translucent plastic funnels were replaced with glass funnels to evaluate a truly clear trap (Fig. 7). Four replicates of seven treatments: 1) yellow bee vane and no lure, 2) PHEROCON Japanese beetle standard trap (yellow top and green cage) with and 3) without Trécé dual lure, 4) PHEROCON Japanese beetle standard trap (green top and green cage) with and 5) without Trécé dual lures, 6) clear plexiglass traps with glass funnels and clear plastic cage bottoms with and 7) without Trécé dual lure were set up on 15 July and continued until 27 July 2017 (12 d total).

Attraction of Bees and Japanese Beetles to Green Plastic versus Glass Cages, Rhode Island 2017. Four replicates of four treatments were tested: 1) Trécé PHEROCON Japanese beetle yellow trap top and glass jar cage with 3 ml geraniol on a 5 ml pad in a 15 ml polycon dispenser, 2) Trécé PHEROCON Japanese beetle yellow trap top and green plastic cage with 3 ml geraniol on a 5 ml pad in a 15 ml polycon dispenser, 3) Trécé Japanese beetle yellow trap top and glass jar cage with a blank pad in a polycon dispenser and 4) Trécé Japanese beetle yellow trap top and green plastic cage with a blank pad in a polycon dispenser. Traps were set out in Kingston, RI, on 28 July 2017 and trapping continued until 18 August 2017 (21 d total).

Attraction of Bees and Japanese Beetles to Different Color Trécé Japanese Beetle Traps, Rhode Island and Tennessee 2018. Six replicates of six treatments all baited with Trécé dual lures: 1) clear plexiglass traps with glass funnels and clear plastic cage bottoms, 2) standard Trécé PHEROCON Japanese beetle yellow trap top and green cage, 3) Trécé Japanese beetle red trap top and red cage (Fig. 8), 4) Trécé Japanese beetle black trap top and black cage (Fig. 9), 5) Trécé Japanese beetle brown trap top and brown cage (Fig. 10), 6) Trécé PHEROCON Japanese beetle green trap top and green cage were tested. Traps were set out on 29 and 18 June 2018 and trapping continued until 24 and 17 August 2018 in Rhode Island, and Tennessee respectively (56 and 60 d).

Statistical analysis. Bee and Japanese beetle counts were log transformed to normalize the data where necessary. Actual bee and Japanese beetle counts are reported in the tables. Following significant analysis of variance (ANOVAs), Least Significant Differences (LSD) tests were used for mean separation of treatments (SAS Institute JMP version 13 2017).

RESULTS

Bees Captured in Japanese Beetle and Bee Vane Traps

2016. A total of 253 *B. impatiens* and 45 *X. virginica* were captured over 14 d at the 2016 mowed site, and 603 *B. impatiens* and 79 *X. virginia* were captured over eight d at the unmowed site (which had lower amounts of lure than the mowed site).

Although other bee species were captured during 2016, *B. impatiens* and *X. virginica* were the two focal species.

2017. A total of 3,749 bees were captured in seven experiments conducted in Rhode Island in 2017. The most common bees captured were *Bombus* spp. and *X. virginica* with 2,440 and 701 captured respectively (Table 1). Bee captures at the Rhode Island study sites in the first four wk period (29 June – 24 July 2017) were much lower (645) than bee captures (3,104) in the second four wk period (27 July – 24 August 2017). Ninety bees were captured at the Ohio study site (Table 1).

2018. A total of 708 bees were captured across three experiments conducted in Rhode Island in 2018. The most common bees captured were *Bombus* spp., other Apidae, and Halictidae with 482, 75, and 75 captured, respectively (Table 2). In Tennessee, a total of 401 bees were captured across two experiments in 2018 and the most common bees captured were *Bombus* spp. and Halictidae with 299 and 47 captured respectively (Table 2). Thirty-four bees were captured in the Ohio experiment and the most common were *Bombus* spp. and other Apidae with 14 and eight captures respectively (Table 2).

Attractiveness of Lures and Lure Components

Attraction of Bees to Individual Floral Lure Components and the Three Component Blend at Mowed and Unmowed Sites, 2016. *Bombus impatiens* was more attracted to geraniol, both alone and as a component in the floral lure blend, than to either eugenol or phenethyl propionate alone at the mowed site (F = 19.74; df = 4,15; P < 0.01) (Table 3). *Xylocopa virginica* was also attracted to geraniol, but only at the higher concentrations present in the single-compound treatment; it was not as attracted to the three-component blend (F = 10.46; df = 4,15; P < 0.01) (Table 3). The attraction of *B. impatiens* to geraniol alone was not significantly different from the three component blend or PEP at the mowed site (Table 4). There was also no significant difference in the attraction of *X. virginica* to geraniol or PEP at the unmowed site (Table 4).

Attraction of Bees and Japanese Beetles to Commercially Prepared Lure Components, 2017. As in 2016, geraniol alone and as a component of the floral lure blend continued to capture more bees than any other treatments in Rhode Island (F = 4.15; df = 7,24; P < 0.01) (Table 5). In Ohio, bee captures were not numerous enough to show significant treatment differences (F = 1.41; df = 7,24; P = 0.25) (Table 6). Although significant treatment differences were found in Japanese beetle trap captures among the lure components in Rhode Island (F =15.06; df = 7,24; P < 0.01) and Ohio (F = 91.98; df = 7,24; P < 0.01), no significant differences were detected in captures between the eugenol and PEP combination and the three lure component blend (Tables 5 and 6).

Attraction of Bees and Japanese beetles to Individual Floral Lure Components and the Three Component Blend in Varying Amounts in Mowed and Unmowed Sites, 2017. There were no significant differences in bee captures at the mowed site where any amount of geraniol was present in a treatment regardless of quantity; however, bee captures in eugenol and PEP alone were also not significantly different from some geraniol containing treatments (F = 5.69; df = 7,24; P < 0.01) (Table 7). At the unmowed site, all geraniol containing treatments captured significantly more bees than any other treatments (F = 24.15; df = 7,24; P < 0.01)

(Table 8). Japanese beetles were significantly more attracted to traps baited with lures containing all three components at both the mowed and unmowed sites ($F = 15.06$; df = 7,24; $P < 0.01$) ($F = 15.06$; df = 7,24; $P < 0.01$) (Tables 7 and 8 respectively). At the mowed site, Japanese beetle captures in eugenol alone were not significantly different from some lures containing all three components. (Table 7)

Attraction of Bees and Japanese Beetles to Commercially Prepared Dual Lures With and Without Geraniol, 2018. The removal of geraniol from the Trécé dual lures significantly reduced the bee captures in standard Trécé PHEROCON Japanese beetle yellow trap top and green cage in Rhode Island but not in the Trécé PHEROCON Japanese beetle green trap top and green cage due to the already low bee captures ($F = 9.47$; df = 3,28; $P < 0.01$) (Table 9). However, in Tennessee and Ohio, removal of geraniol did not result in lower bee captures (Tables 10 and 11 respectively). All green topped traps captured significantly fewer bees than yellow top and green cage traps regardless of the presence of geraniol in Tennessee ($F = 4.68$; df = 3,28; $P < 0.01$) (Table 10) and Ohio ($F = 17.35$; df = 3,28; $P < 0.01$) (Table 11). In all three study locations, there was no significant differences in Japanese beetle capture between traps with or without geraniol regardless of the trap color; RI:($F = 0.66$; df = 3,28; $P = 0.58$); TN:($F = 2.81$; df = 3,28; $P = 0.06$); OH:($F = 2.77$; df = 3,28; $P = 0.06$) (Tables 9-11).

Attraction of Bees and Japanese Beetles to Trécé Japanese Beetle Pheromone Lures, 2018. Japanese beetle traps baited with Trécé Japanese beetle pheromone lures were not significantly more attractive to bees than were unbaited ($F = 9.49$; df = 3,28; $P < 0.01$) (Table 12). Yellow topped traps captured significantly more bees than the all green traps regardless of the presence of the Japanese beetle pheromone lure ($F = 9.49$; df = 3,28; $P < 0.01$) (Table 12). The presence of the pheromone lure significantly increased the Japanese beetle captures in yellow topped traps and all green traps with the yellow topped traps capturing more than the all green traps ($F = 27.25$; df = 3,28; $P < 0.01$) (Table 12).

Attractiveness of Different Trap Colors and Designs

Evaluation of Trap Color and Shields to Reduce Bee Captures at a Mowed Site, 2017. Acetate shields on yellow top and green cage and all green traps did not significantly hinder Japanese beetle captures ($F = 2.94$; df = 5,18; $P = 0.04$) (Table 13), however, only the shields on the yellow top traps significantly reduced bee bycatch ($F = 17.89$; df = 5,18; $P < 0.01$) (Table 13). Traps with green tops captured significantly fewer bees than yellow or clear top traps ($F = 17.89$; df = 5,18; $P < 0.01$) (Table 13).

Evaluation of Trap Color and Design (Translucent Funnel) to Reduce Bee Captures at an Unmowed Site, 2017. There were no significant differences in bee captures in the yellow top and green cage Japanese beetle traps without lures and the yellow bee vane traps (Table 14). Traps with green tops again captured significantly fewer bees than yellow or clear top traps ($F = 16.69$; df = 6,21; $P < 0.01$) (Table 14). Japanese beetles were significantly more attracted to traps baited with the Trécé dual lure than traps without the Trécé dual lure regardless of the trap color or design ($F = 34.53$; df = 6,21; $P < 0.01$) (Table 14).

Evaluation of Trap Color and Design (Glass Funnel) to Reduce Bee Captures at a Unmowed Site, 2017. The yellow bee vane traps with no lures captured as many bees as the standard Japanese beetle trap with or without the dual lure (F = 10.48; df = 6,21; P < 0.01) (Table 15). Traps with green tops again captured significantly fewer bees than yellow or clear top traps with or without lures (Table 15). Japanese beetles were significantly more attracted to traps baited with the Trécé dual lure than traps without the Trécé dual lure regardless of the trap color or design (F = 35.98; df = 6,21; P < 0.01) (Table 15).

Attraction of Bees and Japanese Beetles to Green Plastic versus Glass Cages, 2017. Traps with geraniol lures captured significantly more bees than traps without it (F = 45.45; df = 3,12; P < 0.01) (Table 16). Traps with glass cages captured significantly more bees than traps with green cages (Table 16). Japanese beetles were significantly more attracted to traps baited with geraniol than traps without geraniol (F = 14.47; df = 3,12; P < 0.01) (Table 16).

Attraction of Bees and Japanese Beetles to Different Color Trécé Japanese Beetle Traps, 2018. The clear Japanese beetle traps continued to be the most attractive to bees in Rhode Island, capturing significantly more bees than the yellow top and green cage traps (F = 30.18; df = 5,30; P < 0.01) (Table 17). The yellow topped traps also captured significantly more bees than green, red, black and brown traps in Rhode Island (Table 17). Similar results were recorded in Tennessee where clear traps and yellow topped traps were equally attractive to bees and captured significantly more bees than the green, red, black, and brown traps (F = 9.94; df = 5,30; P < 0.01) (Table 18). In Rhode Island, the all red traps captured only *Bombus* spp. during the entire season (Table 17). Of the bee taxa numerous enough to show significant differences in Rhode Island, *X. virginica* was the only bee species more attracted to yellow top and green cage traps than the clear traps that were more attractive to the other bee taxa. In both Rhode Island and Tennessee, there were no significant differences in Japanese beetle capture between any treatments; RI:($F = 0.56$; df = 5,30; $P = 0.73$); TN:($F = 2.07$; df = 5,30; $P = 0.10$) (Tables 17 and 18).

DISCUSSION

This study found that bycatch of pollinating bees can be minimized by using the floral lure combination of eugenol and phenethyl propionate in the standard ratio (7:3) in all green Japanese beetle traps. These results propose an alternative lure and trap for effective Japanese beetle detection systems that minimize adverse effects on bee pollinators.

Spears et al. (2016) tested multicolor (green canopy, yellow funnel and white bucket) traps with and without *Spodoptera litura* (F.), *Spodoptera littoralis* (Boisduval), or *Helicoverpa armigera* (Hubner) pheromone lures for bycatch of Coccinellidae, Apoidea, and nontarget Lepidoptera. They collected a total of 6,399 bees, belonging to five families, 25 genera, and 57 species in various trap and lure combinations. Aurelian et al. (2015) concluded that some trap and lure combinations were so attractive to beneficial insects that they were considered unacceptable pest management tools. Yellow, white and blue “bee bowls” are used to trap bees (Droege et al. 2010) so it is predictable that other studies (Strange et al. 2011) would find yellow Japanese beetle traps attract and capture bees.

In this study, *B. impatiens* was attracted to geraniol alone and when used as a component of the floral lure blend. *Xylocopa virginica* was primarily attracted to geraniol and not the three component blend. It is interesting that *X. virginica* was not attracted to the blend because it contained the same amount of geraniol as the single component geraniol lure. Geraniol has a vapor pressure of 0.03 mm Hg at 25 degrees Celsius and eugenol has a vapor pressure of 0.0221 mm Hg at 25 degrees Celsius (NCBI 2018), making geraniol a more volatile lure. The combination of geraniol and eugenol might lead to a decreased volatilization of the lure resulting in fewer *X. virginica* captures. Geraniol is a component of many fruits and spices (apple, apricot, blueberry, cherry, citrus fruits, cranberry, currants, grape, papaya, peach, raspberry, blackberry, elderberry, cinnamon, etc.) (Maarse and Visscher 1985) as well as flowers (Tatsuka et al. 1990, Schlotzhauer et al. 1996). Geraniol (along with nerol, citral, nerolic acid, geranic acid, and farnesol) is also a component of Nasanov pheromone, which is used by honey bees (*Apis mellifera* L.) to find their nest entrance, in swarming and to mark rewarding flowers (Winston 1987, Trhlin and Rajchard 2011). Geraniol has been found in the mandibular glands of *Andrena helvola* (L.) and *Andrena labiata* (Fabricius) (Tengo and Bergstrom 1976). Because geraniol is a component of honey bee pheromones, it was expected that traps baited with geraniol would capture honey bees; however, Free (1962) found that five drops of geraniol were repellent to honey bee recruits. Free (1962) did not describe the volume of the five geraniol drops, but five drops from a dropper in our lab yielded 0.16 ml. The commercially available Japanese beetle floral lures have 0.76 ml of geraniol, which may explain the apparent repellency of floral lures to honey bees.

Eugenol and phenethyl propionate (7:3) was the standard lure adopted by State and Federal agencies for surveying Japanese beetles for many years (Ladd and McGovern 1980). Captures of Japanese beetles in the eugenol and phenethyl propionate combination were not significantly different from the three component blend in Rhode Island, Tennessee, or Ohio in 2017 and 2018. Manufacturers may want to offer a ‘bee friendly’ lure and trap color combination to reduce bee captures if further testing confirms that it would not significantly reduce Japanese beetle captures.

Traps that were all green, brown, black, or red captured significantly fewer bees than traps with yellow tops and green cages or clear tops with translucent or glass funnels and clear cages. Traps without lures are also attractive to bees, however, and adding lures containing geraniol alone significantly increased bee bycatch. Several experiments found that traps with translucent or glass funnels and clear plastic or glass cages captured more bees than traps with green cages. Translucent plastic, plexiglass and glass may have a spectral reflectance that is attractive to bees.

The Japanese beetle is under quarantine in several western states (USDA APHIS 2016). The federal quarantine addresses the threat of Japanese beetle transport in aircraft, but does not address the movement of beetles on or in plants, pots, or potting media. Therefore, the National Plant Board developed the national Japanese Beetle Harmonization Plan to protect uninfested states. The latest revisions were effective Jan. 1. 2017 (National Plant Board 2016). The Japanese Beetle Harmonization Plan currently uses Japanese beetle traps to determine the infestation status of states, as part of a detection survey for origin certification, and as part of the

Japanese Beetle Nursery Trapping Program. Category 1 states that are uninfested and maintain a quarantine, Category 2 states that are uninfested or partially infested and may maintain a quarantine, Category 3 states that are partially or generally infested, and Category 4 states that historically are not known to be infested and are not likely to become infested.

Bumble bees vary in their foraging distances. Walther-Hellwig and Frankl (2000) found that greater than 60% of the workers of *Bombus muscorum* L. forage within 100 m of the nest while approximately 40% of *Bombus lapidaries* L. and only 10% of *Bombus terrestris* L. workers forage within 100 m of the nest. Almost 25% of *B. terrestris* were found foraging in habitats between 1,500 and 1,750 m from the nest. The explanation for these differences has to do with colony size, that is, larger colonies need to range over a larger area to find sufficient food (Goulson 2010). Bumble bee species that live in small colonies may be particularly vulnerable where large numbers of Japanese beetle traps are deployed. California annually deploys over 12,000 Japanese beetle traps around airports to intercept Japanese beetles coming in from the eastern U.S (CDFA 2016). General residential trapping is currently conducted at two traps per square mile. If a Japanese beetle is detected, trap density is increased to 50 traps over 2.6 square kilometers. Depending upon the forage availability and the species of bee, these trapping densities could capture a significant number of native bees. Landscape managers and homeowners also use lures and traps to monitor and control Japanese beetles. In this study, the highest collection for the standard yellow top and green cage treatment baited with geraniol captured 206 bees over a 21d period in 2017. In 2016, bee captures would have been considerably higher if the traps were left out for more hours. Bee captures in 2018 may have been reduced due to the high number of bees captured during trapping in 2017.

We have determined that geraniol is the main component in the Japanese beetle floral lure that is most attractive to native bees and that removing it will not significantly reduce Japanese beetle capture. We also have determined that entirely green, brown, black, or red traps are the least attractive to native bees. Companies and regulators can now offer a ‘bee friendly’ trap for monitoring and control purposes.

ACKNOWLEDGEMENTS

We thank Bill Lingren and Valerie McKinney at Trécé, Adair, OK who were very supportive in providing traps and lures per our specifications. We thank Rebecca Gumbrewicz, Nadeer Youssef, Debbie Eskandarnia, Garret Roper, and Joshua Basham for trapping assistance and Kenton Dolinich, Richard Horvath, and Charles Dawson for assistance in plexiglass trap construction. We also thank Dr. Howard S. Ginsberg and Dr. Evan L. Preisser for their review of this manuscript. This is contribution number 5460 of the Rhode Island Agricultural Experiment Station. Use of trade or product names does not imply endorsement by the authors or their institutions.

Table 1. Total number of bees captured 29 June – 24 August in Rhode Island and 5 July – 15 August in Ohio by taxa, 2017.

	Number of bees	
Taxa	Rhode Island	Ohio
Bombus spp.	2,409	31
Xylocopa virginica	687	14
Halicitidae	399	14
Other Apidae	161	25
Andrenidae	78	3
Megachilidae	15	3
Total	3,749	90

Table 2. Total number of bees captured 29 June – 24 August in Rhode Island, 18 June – 17 August in Tennessee, and 9 July – 4 September in Ohio by taxa, 2018.

	Number of bees		
Taxa	Rhode Island	Tennessee	Ohio
Bombus spp.	482	299	14
Xylocopa virginica	43	21	1
Halicitidae	75	47	5
Other Apidae	75	27	8
Andrenidae	27	0	4
Megachilidae	6	7	2
Total	708	401	34

Table 3. Captures of *Bombus impatiens* and *Xylocopa virginica* in Japanese beetle traps with various lure components and amounts at a mowed site, 5 – 19 Aug. 2016, Kingston, RI.

		$\bar{X} \pm$ SEM[a]		Total No. Bees Captured	
Lure	ml	*B. impatiens*	*X. virginica*	*B. impatiens*	*X. virginica*
Geraniol	3.0	22.3 ± 3.7a	8.8 ± 2.5a	89	35
Eugenol	3.0	2.8 ± 0.9b	0.3 ± 0.3b	11	1
Penethyl propionate	3.0	3.5 ± 1.9b	1.3 ± 0.6b	14	5
G/E/PEP[b]	1.0 of each	33.8 ± 5.2a	1.0 ± 0.6b	135	4
Control	---	1.0 ± 0.6b	0.0 ± 0.0b	4	0

[a]Means in the same column followed by the same letters are not significantly different, $\alpha = 0.05$, LSD test, *B. impatiens:* $F = 19.74$; df = 4,15; $P < 0.01$. *X. virginica*: $F = 10.46$; df = 4,15; $P < 0.01$. [b]G = geraniol, E = eugenol, PEP = phenethyl propionate.

Table 4. Captures of *Bombus impatiens* and *Xylocopa virginica* in Japanese beetle traps with various lure components and amounts at an unmowed site, 11 – 19 Aug. 2016, Kingston, RI.

		$\bar{X} \pm$ SEM[a]		Total No. Bees Captured	
Lure	ml	*B. impatiens*	*X. virginica*	*B. impatiens*	*X. virginica*
Geraniol	0.7	54.0 ± 13.0ab	9.8 ± 1.9a	216	39
Eugenol	1.6	10.3 ± 1.7cd	1.0 ± 0.7c	41	4
Penethyl propionate	0.7	22.3 ± 7.0bc	5.5 ± 1.7ab	89	22
G/E/PEP[b]	0.7/1.6/0.7	59.0 ± 8.6a	3.5 ± 0.9b	236	14
Control	---	5.3 ± 3.1d	0.0 ± 0.0c	21	0

[a]Means in the same column followed by the same letters are not significantly different, $\alpha = 0.05$, LSD test, *B. impatiens:* $F = 11.28$; df = 4,15; $P < 0.01$. *X. virginica*: $F = 13.51$; df = 4,15; $P < 0.01$. [b]G = geraniol, E = eugenol, PEP = phenethyl propionate.

Table 5. Captures of *Popillia japonica* and bees in Japanese beetle traps with various lure components and amounts, 29 June – 24 August 2017, Kingston, RI.

		$\bar{X} \pm$ SEM[a]				
Lure	ml	*P. japonica*	*Bombus* spp.	*X. virginica*	Other Apidae	Andrenidae
Geraniol	0.76	228.5 ± 92.3cd	19.8 ± 5.8a	0.8 ± 0.5ab	0.5 ± 0.3	0.8 ± 0.5
Eugenol	1.78	177.8 ± 54.4cd	1.8 ± 0.3c	0.0 ± 0.0c	1.0 ± 0.5	2.0 ± 1.1
PEP	0.76	92.0 ± 47.0de	4.3 ± 1.4bc	0.0 ± 0.0c	0.3 ± 0.3	0.5 ± 0.3
E/PEP[b]	1.78/0.76	1,331.0 ± 451.9ab	4.8 ± 2.5bc	0.3 ± 0.3c	1.0 ± 0.5	1.8 ± 0.8
G/E/PEP[b]	0.76/1.78/0.76	1,224.0 ± 273.3ab	20.3 ± 9.0a	1.0 ± 0.5a	1.0 ± 0.5	1.0 ± 0.5
Pheromone	1 mg	595.8 ± 209.5bc	2.5 ± 1.0c	0.0 ± 0.0c	0.3 ± 0.3	0.3 ± 0.3
G/E/PEP + pher.[b]	0.76/1.78/0.76 + 1 mg	1,716.3 ± 488.7a	11.3 ± 3.7ab	0.3 ± 0.3bc	0.5 ± 0.5	0.5 ± 0.3
Control	---	20.3 ± 4.5e	4.0 ± 1.3bc	0.0 ± 0.0	0.5 ± 0.5	0.3 ± 0.3

Table 5. (continued).

		$\bar{X} \pm$ SEM[a]			
Lure	ml	Halictidae	Megachilidae	All Bees	Total No. Bees Captured
Geraniol	0.76	5.8 $\pm$ 2.8	0.0 $\pm$ 0.0	27.5 $\pm$ 8.1a	110
Eugenol	1.78	1.5 $\pm$ 0.3	0.3 $\pm$ 0.3	6.5 $\pm$ 1.3bc	26
PEP	0.76	0.5 $\pm$ 0.3	0.0 $\pm$ 0.0	6.3 $\pm$ 1.4bc	25
E/PEP[b]	1.78/0.76	1.3 $\pm$ 0.6	0.0 $\pm$ 0.0	9.0 $\pm$ 3.0bc	36
G/E/PEP[b]	0.76/1.78/0.76	0.8 $\pm$ 0.5	0.3 $\pm$ 0.3	24.3 $\pm$ 9.1a	97
Pheromone	1 mg	1.5 $\pm$ 0.9	0.0 $\pm$ 0.0	4.8 $\pm$ 1.5c	19
G/E/PEP + pher.[b]	0.76/1.78/0.76 + 1 mg	1.0 $\pm$ 0.7	0.0 $\pm$ 0.0	13.5 $\pm$ 4.1ab	54
Control	---	1.3 $\pm$ 0.3	0.0 $\pm$ 0.0	6.0 $\pm$ 1.1bc	24

Table 5. (continued).

[a]Means in the same column followed by the same letters are not significantly different, $\alpha = 0.05$, LSD test, *Popillia. japonica*: F = 15.06; df = 7,24; $P < 0.01$. *Bombus*: F = 5.13; df = 7,24; $P < 0.01$. *Xylocopa virginica*: F = 2.44; df = 7,24; $P < 0.05$. Other Apidae: F = 0.79; df = 7,24; $P = 0.60$. Andrenidae: F = 1.19; df = 7,24, $P = 0.35$. Halictidae: F = 2.33; df = 7,24; $P = 0.06$. Megachilidae: F = 0.86; df = 7,24; $P = 0.55$. All Bees: F = 4.15; df = 7,24; $P < 0.01$. [b]G = geraniol, E = eugenol, PEP = phenethyl propionate, pher. = pheromone.

Table 6. Captures of *Popillia japonica* and bees in Japanese beetle traps with various lure components and amounts, 5 July – 15 August 2017, Wooster, OH.

		$\bar{X}$ ± SEM[a]				
Lure	ml	*P. japonica*	*Bombus* spp.	*X. virginica*	Other Apidae	Andrenidae
Geraniol	0.76	3,171.8 ± 813.4bc	1.3 ± 0.3	2.3 ± 1.3a	0.5 ± 0.3	0.0 ± 0.0
Eugenol	1.78	4,888.3 ± 818.7b	0.8 ± 0.8	0.0 ± 0.0c	1.3 ± 0.3	0.0 ± 0.0
PEP	0.76	968.3 ± 204.9d	0.8 ± 0.5	0.3 ± 0.3bc	0.5 ± 0.3	0.3 ± 0.3
E/PEP[b]	1.78/0.76	20,757.3 ± 2798.9a	0.3 ± 0.3	0.0 ± 0.0c	1.5 ± 0.6	0.0 ± 0.0
G/E/PEP[b]	0.76/1.78/0.76	22,271.0 ± 2106.3a	2.5 ± 1.0	1.0 ± 0.5ab	0.8 ± 0.3	0.3 ± 0.3
Pheromone	1 mg	2809.5 ± 167.8c	0.5 ± 0.3	0.0 ± 0.0c	0.3 ± 0.3	0.0 ± 0.0
G/E/PEP + pher.[b]	0.76/1.78/0.76 + 1 mg	29,591.3 ± 4437.7a	0.5 ± 0.3	0.0 ± 0.0c	1.3 ± 0.3	0.0 ± 0.0
Control	---	225.8 ± 59.33e	1.3 ± 0.8	0.0 ± 0.0c	0.3 ± 0.3	0.3 ± 0.3

Table 6. (continued).

Lure	ml	$\bar{X} \pm$ SEM[a]			
		Halictidae	Megachilidae	All Bees	Total No. Bees Captured
Geraniol	0.76	0.5 ± 0.5	0.0 ± 0.0	4.5 ± 1.5	18
Eugenol	1.78	0.3 ± 0.3	0.0 ± 0.0	2.3 ± 0.7	9
PEP	0.76	0.8 ± 0.3	0.3 ± 0.3	2.8 ± 0.5	11
E/PEP[b]	1.78/0.76	0.5 ± 0.3	0.0 ± 0.0	2.3 ± 0.9	9
G/E/PEP[b]	0.76/1.78/0.76	0.3 ± 0.3	0.3 ± 0.3	5.0 ± 1.5	20
Pheromone	1 mg	0.3 ± 0.3	0.3 ± 0.3	1.3 ± 0.5	5
G/E/PEP + pher.[b]	0.76/1.78/0.76 + 1 mg	0.8 ± 0.5	0.8 ± 0.5	2.5 ± 0.6	10
Control	---	0.3 ± 0.3	0.3 ± 0.3	2.0 ± 1.3	8

Table 6. (continued).

[a]Means in the same column followed by the same letters are not significantly different, $\alpha = 0.05$, LSD test, *Popillia japonica*: $F = 91.98$; df = 7,24; $P < 0.01$. *Bombus:* $F = 1.16$; df = 7,24; $P = 0.36$. *Xylocopa virginica*: $F = 4.23$; df = 7,24; $P < 0.01$. Other Apidae: $F = 2.11$; df = 7,24; $P = 0.08$. Andrenidae: $F = 0.71$; df = 7,24; $P = 0.66$. Halictidae: $F = 0.46$; df = 7,24; $P = 0.86$. Megachilidae: $F = 0.71$; df = 7,24; $P = 0.66$. All Bees: $F = 1.41$; df = 7,24; $P = 0.25$. [b]G = geraniol, E = eugenol, PEP = phenethyl propionate, pher. = pheromone.

Table 7. Captures of *Popillia japonica* and bees in Japanese beetle traps with various lure components and amounts at a mowed site, 28 July – 18 August 2017, Kingston, RI.

		$\bar{X} \pm$ SEM[a]				
Lure	ml	*P. japonica*	*Bombus* spp.	*X. virginica*	Other Apidae	Andrenidae
Geraniol	3.0	4.5 ± 1.2c	20.8 ± 3.9a	4.5 ± 0.9a	0.5 ± 0.5	0.0 ± 0.0
Eugenol	3.0	8.5 ± 2.5bc	2.3 ± 0.3c	0.0 ± 0.0c	2.3 ± 0.8	0.0 ± 0.0
PEP	3.0	3.8 ± 0.9c	8.0 ± 1.4b	2.3 ± 0.8ab	0.8 ± 0.8	0.0 ± 0.0
G/E/PEP[b]	0.7/1.6/0.7	17.3 ± 1.7a	18.5 ± 6.4ab	1.0 ± 0.4bc	1.0 ± 0.7	0.3 ± 0.3
Geraniol	0.76	4.3 ± 0.3c	10.8 ± 3.7ab	5.5 ± 2.1a	0.5 ± 0.5	0.0 ± 0.0
G/E/PEP[b]	0.76/1.78/0.76	14.0 ± 2.6ab	21.0 ± 7.3ab	3.5 ± 0.9a	0.5 ± 0.3	0.3 ± 0.3
G/E/PEP + pher.[b]	0.76/1.78/0.76 + 1 mg	24.5 ± 1.8a	20.3 ± 7.0ab	3.8 ± 0.9a	0.5 ± 0.3	0.0 ± 0.0
Control	---	1.8 ± 1.0d	3.0 ± 0.7c	0.0 ± 0.0c	0.8 ± 0.3	0.0 ± 0.0

Table 7. (continued).

Lure	ml	$\bar{X} \pm$ SEM[a]			Total No. Bees Captured
		Halictidae	Megachilidae	All Bees	
Geraniol	3.0	3.0 ± 0.8	0.0 ± 0.0b	28.8 ± 4.2a	115
Eugenol	3.0	2.5 ± 0.5	0.0 ± 0.0b	7.0 ± 0.9cd	28
PEP	3.0	2.0 ± 0.4	0.5 ± 0.3a	13.5 ± 2.1bc	54
G/E/PEP[b]	0.7/1.6/0.7	1.3 ± 0.5	0.0 ± 0.0b	22.0 ± 6.2ab	88
Geraniol	0.76	1.0 ± 0.6	0.0 ± 0.0b	17.8 ± 6.6abc	71
G/E/PEP[b]	0.76/1.78/0.76	1.8 ± 0.9	0.0 ± 0.0b	27.0 ± 6.8ab	108
G/E/PEP + pher.[b]	0.76/1.78/0.76 + 1 mg	2.0 ± 0.9	0.0 ± 0.0b	26.5 ± 7.5ab	106
Control	---	1.5 ± 0.5	0.0 ± 0.0b	5.3 ± 1.3d	21

Table 7. (continued).

[a]Means in the same column followed by the same letters are not significantly different, $\alpha = 0.05$, LSD test, *Popillia japonica*: F = 15.06; df = 7,24; $P < 0.01$. *Bombus*: F= 7.21; df = 7,24; $P < 0.01$. *Xylocopa virginica*: F = 10.98; df = 7,24; $P < 0.01$. Other Apidae: F = 1.08; df = 7,24; P = 0.41. Andrenidae: F = 0.86; df; 7,24; P = 0.55. Halictidae: F = 0.93; df = 7,24; P = 0.50. Megachilidae: F = 3.00; df = 7,24; P = 0.02. All Bees: F = 5.69; df = 7,24; $P < 0.01$. [b]G = geraniol, E = eugenol, PEP = phenethyl propionate, pher. = pheromone.

Table 8. Captures of *Popillia japonica* and bees in Japanese beetle traps with various lure components and amounts at an unmowed site, 28 July – 18 August 2017, Kingston, RI.

		$\bar{X} \pm$ SEM[a]				
Lure	ml	*P. japonica*	*Bombus* spp.	*X. virginica*	Other Apidae	Andrenidae
Geraniol	3.0	7.3 ± 1.3bc	54.8 ± 6.9a	24.3 ± 4.2a	0.3 ± 0.3	0.3 ± 0.3
Eugenol	3.0	9.3 ± 2.5b	8.0 ± 1.5cd	0.0 ± 0.0c	2.8 ± 1.8	1.0 ± 0.0
PEP	3.0	4.3 ± 2.9c	12.5 ± 1.2c	3.0 ± 2.4b	2.0 ± 0.9	0.0 ± 0.0
G/E/PEP[b]	0.7/1.6/0.7	41.3 ± 7.6a	55.0 ± 14.2a	11.3 ± 0.4a	1.5 ± 0.5	0.8 ± 0.5
Geraniol	0.76	5.8 ± 0.6bc	28.0 ± 5.8b	15.5 ± 5.1a	1.5 ± 0.3	0.5 ± 0.3
G/E/PEP[b]	0.76/1.78/0.76	39.0 ± 4.7a	39.5 ± 3.3ab	17.5 ± 2.5a	1.3 ± 0.5	0.8 ± 0.5
G/E/PEP + pher. [b]	0.76/1.78/0.76 + 1 mg	68.0 ± 14.5a	57.0 ± 8.4a	15.8 ± 3.4a	1.3 ± 0.6	0.3 ± 0.3
Control	---	0.3 ± 0.3d	6.5 ± 2.9d	0.3 ± 0.3bc	1.5 ± 0.3	0.0 ± 0.0

Table 8. (continued).

Lure	ml	$\bar{X} \pm$ SEM[a] Halictidae	Megachilidae	All Bees	Total No. Bees Captured
Geraniol	3.0	6.3 ± 1.1ab	0.0 ± 0.0	85.8 ± 11.3a	343
Eugenol	3.0	1.5 ± 0.3c	0.5 ± 0.5	13.8 ± 2.4cd	55
PEP	3.0	3.5 ± 1.3bc	0.0 ± 0.0	21.3 ± 2.3c	85
G/E/PEP[b]	0.7/1.6/0.7	3.0 ± 1.1bc	0.3 ± 0.3	71.8 ± 14.7ab	287
Geraniol	0.76	7.8 ± 1.7a	0.0 ± 0.0	53.3 ± 10.1b	213
G/E/PEP[b]	0.76/1.78/0.76	1.8 ± 1.1c	0.0 ± 0.0	60.8 ± 4.6ab	243
G/E/PEP + pher.[b]	0.76/1.78/0.76 + 1 mg	3.3 ± 0.9bc	0.0 ± 0.0	75.0 ± 8.1ab	300
Control	---	2.3 ± 0.9c	0.0 ± 0.0	10.5 ± 2.7d	42

Table 8. (continued).

[a]Means in the same column followed by the same letters are not significantly different, $\alpha = 0.05$, LSD test, *Popillia japonica*: $F = 15.06$; df = 7,24; $P < 0.01$. *Bombus*: $F = 17.36$; df = 7,24; $P < 0.01$. *Xylocopa virginica*: $F = 22.37$; df = 7,24; $P < 0.01$. Other Apidae: $F = 0.95$; df = 7,24; $P = 0.49$. Andrenidae: $F = 1.90$; df = 7,24; $P = 0.11$. Halictidae: $F = 3.62$; df = 7,24; $P < 0.01$. Megachilidae: $F = 0.87$; df = 7,24; $P = 0.54$. All Bees: $F = 24.15$; df = 7,24; $P < 0.01$. [b]G = geraniol, E = eugenol, PEP = phenethyl propionate, pher. = pheromone.

Table 9. Captures of *Popillia japonica* and bees in Japanese beetle traps with various trap types and lure components, 29 June – 24 August 2018, Kingston, RI.

		$\bar{X} \pm$ SEM[a]				
Trap type	Lure	*P. japonica*	*Bombus* spp.	*X. virginica*	Other Apidae	Andrenidae
Yellow top and green cage	Dual	1,048.9 ± 210.0	5.5 ± 1.6a	0.4 ± 0.2	1.4 ± 0.5	0.0 ± 0.0
Yellow top and green cage	Dual (- geraniol)	864.0 ± 176.0	3.6 ± 0.9a	0.1 ± 0.1	0.8 ± 0.4	0.3 ± 0.2
Green top and green cage	Dual	882.0 ± 172.0	0.6 ± 0.3b	0.0 ± 0.0	0.3 ± 0.2	0.1 ± 0.1
Green top and green cage	Dual (- geraniol)	695.1 ± 148.4	0.4 ± 0.2b	0.0 ± 0.0	0.3 ± 0.2	0.0 ± 0.0

Table 9. (continued).

		$\bar{X} \pm$ SEM[a]			
Trap type	Lure	Halictidae	Megachilidae	All Bees	Total No. Bees Captured
Yellow top and green cage	Dual	1.5 ± 0.6a	0.1 ± 0.1	8.9 ± 2.2a	71
Yellow top and green cage	Dual (- geraniol)	0.3 ± 0.3b	0.0 ± 0.0	5.0 ± 1.2b	40
Green top and green cage	Dual	0.1 ± 0.1b	0.0 ± 0.0	1.1 ± 0.2c	9
Green top and green cage	Dual (- geraniol)	0.0 ± 0.0b	0.0 ± 0.0	0.6 ± 0.2c	5

[a]Means in the same column followed by the same letters are not significantly different, $\alpha = 0.05$, LSD test, *Popillia japonica:* $F = 0.66$; df = 3,28; $P = 0.58$. *Bombus*: $F = 6.77$; df = 3,28; $P < 0.01$. *Xylocopa virginica:* $F = 2.55$; df = 3,28; $P = 0.08$. Other Apidae: $F = 2.62$; df = 3,28; $F = 0.07$. Andrenidae: $F = 1.35$; df = 3,28; $P = 0.28$. Halictidae: $F = 4.44$; df = 3,28; $P = 0.01$. Megachilidae: $F = 1.00$; df = 3,28; $P = 0.41$. All Bees: $F = 9.47$; df = 3,28; $P < 0.01$.

Table 10. Captures of *Popillia japonica* and bees in Japanese beetle traps with various trap types and lure components, 18 June – 17 August 2018, McMinnville, TN.

		$\bar{X} \pm$ SEM[a]				
Trap type	Lure	*P. japonica*	*Bombus* spp.	*X. virginica*	Other Apidae	Andrenidae
Yellow top and green cage	Dual	946.5 ± 100.6	3.5 ± 0.9ab	0.3 ± 0.2	0.3 ± 0.2	0.0 ± 0.0
Yellow top and green cage	Dual (- geraniol)	719.6 ± 78.2	5.6 ± 0.9a	0.0 ± 0.0	0.4 ± 0.2	0.0 ± 0.0
Green top and green cage	Dual	906.8 ± 93.7	2.4 ± 0.8b	0.6 ± 0.3	0.0 ± 0.0	0.0 ± 0.0
Green top and green cage	Dual (- geraniol)	653.8 ± 61.0	2.1 ± 0.5b	0.1 ± 0.1	0.1 ± 0.1	0.0 ± 0.0

Table 10. (continued).

		$\bar{X} \pm$ SEM[a]			
Trap type	Lure	Halictidae	Megachilidae	All Bees	Total No. Bees Captured
Yellow top and green cage	Dual	1.3 ± 0.6	0.1 ± 0.1	5.4 ± 0.9ab	43
Yellow top and green cage	Dual (- geraniol)	0.5 ± 0.2	0.1 ± 0.1	6.6 ± 0.9a	53
Green top and green cage	Dual	0.1 ± 0.1	0.1 ± 0.1	3.3 ± 1.0bc	26
Green top and green cage	Dual (- geraniol)	0.3 ± 0.2	0.0 ± 0.0	2.6 ± 0.6c	21

[a]Means in the same column followed by the same letters are not significantly different, $\alpha = 0.05$, LSD test, *Popillia japonica:* $F = 2.81$; df = 3,28; $P = 0.06$. *Bombus*: $F = 3.89$; df = 3,28; $P < 0.02$. *Xylocopa virginica:* $F = 2.61$; df = 3,28; $P = 0.07$. Other Apidae: $F = 1.37$; df = 3,28; $P = 0.27$. Halictidae: $F = 2.20$; df = 3,28; $P = 0.11$. Megachilidae: $F = 0.33$; df = 3,28; $P = 0.80$. All Bees: $F = 4.68$; df = 3,28; $P < 0.01$.

Table 11. Captures of *Popillia japonica* and bees in Japanese beetle traps with various trap types and lure components, 9 July – 4 September 2018, Wooster, OH.

		$\bar{X} \pm$ SEM[a]				
Trap type	Lure	*P. japonica*	*Bombus*	*X. virginica*	Other Apidae	Andrenidae
Yellow top and green cage	Dual	3,562.4 ± 593.0	0.8 ± 0.2a	0.1 ± 0.1	0.6 ± 0.2a	0.0 ± 0.0b
Yellow top and green cage	Dual (- geraniol)	1,423.9 ± 192.7	0.8 ± 0.3a	0.0 ± 0.0	0.3 ± 0.2ab	0.5 ± 0.2a
Green top and green cage	Dual	2,546.3 ± 581.8	0.1 ± 0.1b	0.0 ± 0.0	0.1 ± 0.1b	0.0 ± 0.0b
Green top and green cage	Dual (- geraniol)	2,402.0 ± 613.5	0.1 ± 0.1b	0.0 ± 0.0	0.0 ± 0.0b	0.0 ± 0.0b

Table 11. (continued).

		$\bar{X} \pm$ SEM[a]			
Trap type	Lure	Halictidae	Megachilidae	All Bees	Total No. Bees Captured
Yellow top and green cage	Dual	0.3 ± 0.2	0.1 ± 0.1	1.9 ± 0.2a	15
Yellow top and green cage	Dual (- geraniol)	0.4 ± 0.2	0.1 ± 0.1	2.0 ± 0.4a	16
Green top and green cage	Dual	0.0 ± 0.0	0.0 ± 0.0	0.3 ± 0.2b	2
Green top and green cage	Dual (- geraniol)	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.1b	1

[a]Means in the same column followed by the same letters are not significantly different, $\alpha = 0.05$, LSD test, *Popillia japonica:* F = 2.77; df = 3,28; $P = 0.06$. *Bombus*: F = 3.33; df = 3,28; $P = 0.03$. *Xylocopa virginica:* F = 1.00; df = 3,28; $P = 0.41$. Other Apidae: F = 3.84; df = 3,28; P = 0.02. Andrenidae: F = 7.00; df = 3,28; $P < 0.01$. Halictidae: F = 2.33; df = 3,28; $P = 0.10$. Megachilidae: F = 0.67; df = 3,28; $P = 0.58$. All Bees: F = 17.35; df = 3,28; $P < 0.01$.

Table 12. Captures of *Popillia japonica* and bees in Japanese beetle traps with various trap types with and without a pheromone lure, 29 June – 24 August 2018, Kingston, RI.

		$\bar{X} \pm$ SEM[a]				
Trap type	Lure	*P. japonica*	*Bombus*	*X. virginica*	Other Apidae	*Andrenidae*
Yellow top/green cage	Pheromone	28.3 ± 3.2a	2.3 ± 0.3a	0.0 ± 0.0	0.1 ± 0.1	0.1 ± 0.1
Yellow top/green cage	Blank	8.3 ± 1.3c	2.1 ± 0.7a	0.0 ± 0.0	0.1 ± 0.1	0.1 ± 0.1
Green top/green cage	Pheromone	17.25 ± 2.2b	0.4 ± 0.2b	0.0 ± 0.0	0.1 ± 0.1	0.0 ± 0.0
Green top/green cage	Blank	3.25 ± 1.0c	0.1 ± 0.1b	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.1

Table 12. (continued).

Trap type	Lure	$\bar{X} \pm$ SEM[a] *Halictidae*	*Megachilidae*	All Bees	Total No. Bees Captured
Yellow top/green cage	Pheromone	0.8 $\pm$ 0.3	0.0 $\pm$ 0.0	3.3 $\pm$ 0.4a	26
Yellow top/green cage	Blank	0.6 $\pm$ 0.3	0.3 $\pm$ 0.2	3.3 $\pm$ 0.8a	26
Green top/green cage	Pheromone	0.1 $\pm$ 0.1	0.0 $\pm$ 0.0	0.6 $\pm$ 0.3b	5
Green top/green cage	Blank	0.3 $\pm$ 0.2	0.0 $\pm$ 0.0	0.5 $\pm$ 0.3b	4

[a]Means in the same column followed by the same letters are not significantly different, $\alpha = 0.05$, LSD test, *Popillia japonica*: $F = 27.25$; df = 3,28; $P < 0.01$. *Bombus*: $F = 8.55$; df = 3,28; $P = 0.01$. Other Apidae: $F = 0.33$; df = 3,28; $P = 0.80$. Andrenidae: $F = 0.33$; df = 3,28; $P = 0.80$. Halictidae: $F = 2.03$; df = 3,28; $P = 0.13$. Megachilidae: $F = 2.33$; df = 3,28; $P = 0.10$. All Bees: $F = 9.49$; df = 3,28; $P < 0.01$.

Table 13. Captures of *Popillia japonica* and bees in various color Japanese beetle traps with Trécé dual lures with and without shields, 3 – 26 July 2017, Kingston, RI.

		$\bar{X} \pm$ SEM[a]		
Trap type	Lure	*P. japonica*	All Bees	Total No. Bees Captured
Yellow top/green cage	dual	101.8 ± 22.8a	3.3 ± 1.0a	13
Yellow top/green cage/shield	dual	122.5 ± 24.2a	0.8 ± 0.5b	3
Green top/green cage	dual	79.3 ± 18.8ab	0.3 ± 0.3b	1
Green top/green cage/shield	dual	85.3 ± 17.8a	0.0 ± 0.0b	0
Clear plexiglass top/translucent funnel/clear cage	dual	85.5 ± 9.4a	4.5 ± 0.6a	18
Clear plexiglass top/translucent funnel/clear cage/shield	dual	46.8 ± 12.1b	4.0 ± 0.4a	16

Table 13. (continued).

[a]Means in the same column followed by the same letters are not significantly different, $\alpha = 0.05$, LSD test, *Popillia japonica*: $F = 2.94$; df = 5,18; $P = 0.04$. All Bees: $F = 17.89$; df = 5,18; $P < 0.01$.

Table 14. Captures of *Popillia japonica* and bees in various color bee and Japanese beetle traps with and without Trécé dual lures, 4 – 15 July 2017, Kingston, RI.

Trap type	lure	$\bar{X} \pm$ SEM[a]		Total No. Bees Captured
		P. japonica	All Bees	
Yellow bee vane trap	---	0.5 ± 0.3b	2.3 ± 0.5bc	9
Yellow top and green cage	dual	58.3 ± 10.6a	6.5 ± 1.7a	26
Yellow top and green cage	---	2.0 ± 1.2b	1.3 ± 0.3cd	5
Green top and green cage	dual	67.5 ± 33.9a	0.8 ± 0.5de	3
Green top and green cage	---	0.0 ± 0.0b	0.0 ± 0.0e	0
Clear plexiglass top and translucent funnel and clear cage	dual	57.0 ± 16.6a	5.0 ± 0.7a	20
Clear plexiglass top and translucent funnel and clear cage	---	1.3 ± 0.8b	4.3 ± 1.3ab	17

Table 14. (continued).

[a]Means in the same column followed by the same letters are not significantly different, $\alpha = 0.05$, LSD test, *Popillia japonica*: $F = 34.53$; df = 6,21; $P < 0.01$. All Bees: $F = 16.69$; df = 6,21; $P < 0.01$.

Table 15. Captures of *Popillia japonica* and bees in various color bee and Japanese beetle traps with and without Trécé dual lures, 15 – 27 July 2017, Kingston, RI.

		$\bar{X} \pm$ SEM[a]		
Trap type	lure	*P. japonica*	All Bees	Total No. Bees Captured
Yellow bee vane	---	2.5 ± 1.2bc	3.5 ± 0.3ab	14
Yellow top and green cage	dual	130.0 ± 58.6a	4.0 ± 1.2ab	16
Yellow top and green cage	---	3.5 ± 1.3b	3.3 ± 0.7b	13
Green top and green cage	dual	66.0 ± 13.3a	0.3 ± 0.3c	1
Green top and green cage	---	1.8 ± 0.9bc	0.3 ± 0.3c	1
Clear plexiglass top and transparent funnel and clear cage	dual	89.8 ± 19.4a	9.3 ± 3.3a	37
Clear plexiglass top and transparent funnel and clear cage	---	0.5 ± 0.3c	4.0 ± 1.2ab	16

Table 15. (continued).

[a]Means in the same column followed by the same letters are not significantly different, $\alpha = 0.05$, LSD test, *Popillia japonica*: $F = 35.98$; df = 6,21; $P < 0.01$. All Bees: $F = 10.48$; df = 6,21; $P < 0.01$.

Table 16. Captures of *Popillia japonica* and bees in various color Japanese beetle traps with and without geraniol, 28 July – 18 August 2017, Kingston, RI.

		$\bar{X}$ ± SEM[a]				
Lure / trap type	ml	*P. japonica*	*Bombus* spp.	*X. virginica*	Other Apidae	Andrenidae
Geraniol /Yellow top / glass cage	3.0	14.3 ± 2.1a	60.3 ± 3.4a	29.0 ± 4.7a	1.0 ± 0.4	0.3 ± 0.3
Geraniol / Yellow top / green cage	3.0	13.5 ± 3.0a	18.8 ± 5.0b	30.5 ± 4.4a	0.3 ± 0.3	1.0 ± 0.7
Control/ Yellow top / glass cage	---	1.5 ± 0.6b	9.5 ± 1.3b	0.0 ± 0.0b	0.5 ± 0.3	0.8 ± 0.5
Control / Yellow top / green cage	---	2.0 ± 0.9b	4.8 ± 1.8c	0.3 ± 0.3b	0.3 ± 0.3	0.0 ± 0.0

Table 16. (continued).

		$\bar{X} \pm$ SEM[a]			
Lure / trap type	ml	Halictidae	Megachilidae	All Bees	Total No. Bees Captured
Geraniol /Yellow top / glass cage	3.0	5.5 $\pm$ 1.5a	0.0 $\pm$ 0.0	95.5 $\pm$ 5.3a	382
Geraniol / Yellow top / green cage	3.0	1.0 $\pm$ 0.6b	0.0 $\pm$ 0.0	51.5 $\pm$ 8.8b	206
Control/ Yellow top / glass cage	---	4.8 $\pm$ 0.8a	0.0 $\pm$ 0.0	15.5 $\pm$ 1.7c	62
Control / Yellow top / green cage	---	0.8 $\pm$ 0.8b	0.3 $\pm$ 0.3	6.3 $\pm$ 1.8d	25

[a]Means in the same column followed by the same letters are not significantly different, $\alpha = 0.05$, LSD test, *Popillia japonica*: $F = 14.47$; df = 3,12; $P < 0.01$. *Bombus*: $F = 23.43$; df = 3,12; $P < 0.01$. *Xylocopa virginica*: $F = 180.48$; df = 3,12; $P < 0.01$. Other Apidae: $F = 1.17$; df = 3,12; $P = 0.36$. Andrenidae: $F = 1.09$; df = 3,12; $P = 0.39$. Halictidae: $F = 7.71$; df = 3,12; $P < 0.01$. Megachilidae: $F = 1.00$; df = 3,12; $P = 0.43$. All Bees: $F = 45.45$; df = 3,12; $P < 0.01$.

Table 17. Captures of *Popillia japonica* and bees in various color Japanese beetle traps baited with Trécé dual lures, 29 June – 24 August 2018, Kingston, RI.

		$\bar{X} \pm$ SEM[a]				
Trap type	Lure	*P. japonica*	*Bombus*	*Xylocopa*	Other Apidae	Andrenidae
Clear	Dual	304.0 ± 65.2	38.0 ± 8.5a	1.0 ± 0.0b	7.8 ± 1.0a	2.0 ± 0.7a
Yellow top and green cage	Dual	353.2 ± 83.2	18.0 ± 2.7b	5.2 ± 1.1a	0.7 ± 0.3b	1.2 ± 0.7ab
Red	Dual	230.0 ± 53.5	2.3 ± 0.3c	0.0 ± 0.0c	0.0 ± 0.0b	0.0 ± 0.0b
Black	Dual	265.3 ± 58.8	0.8 ± 0.2c	0.2 ± 0.2c	0.0 ± 0.0b	0.2 ± 0.2b
Brown	Dual	221.7 ± 60.1	0.5 ± 0.3c	0.2 ± 0.2 c	0.0 ± 0.0b	0.2 ± 0.2b
Green	Dual	260.0 ± 70.4	0.7 ± 0.2c	0.0 ± 0.0c	0.0 ± 0.0b	0.0 ± 0.0b

Table 17. (continued).

Trap type	Lure	Halictidae	Megachilidae	All Bees	Total No. Bees Captured
		$\bar{X} \pm$ SEM[a]			
Clear	Dual	4.8 ± 0.6a	0.2 ± 0.2	53.8 ± 8.8a	323
Yellow top and green cage	Dual	2.7 ± 0.6b	0.2 ± 0.2	27.8 ± 4.2b	167
Red	Dual	0.0 ± 0.0c	0.0 ± 0.0	2.3 ± 0.3c	14
Black	Dual	0.0 ± 0.0c	0.0 ± 0.0	1.2 ± 0.3c	7
Brown	Dual	0.2 ± 0.2c	0.0 ± 0.0	1.0 ± 0.4c	6
Green	Dual	0.0 ± 0.0c	0.2 ± 0.2	0.8 ± 0.2c	5

Table 17. (continued).

[a]Means in the same column followed by the same letters are not significantly different, $\alpha = 0.05$, LSD test, *Popillia japonica*: $F = 0.56$; df = 5,30; $P = 0.73$. *Bombus*: $F = 17.50$; df = 5,30; $P < 0.01$. *Xylocopa virginica*: $F = 18.41$; df = 5,30; $P < 0.01$. Other Apidae: $F = 55.69$; df = 5,30; $P < 0.01$. Andrenidae $F = 4.26$; df = 5,30; $P < 0.01$. Halictidae: $F = 35.49$; df = 5,30; $P < 0.01$. Megachilidae: $F = 0.60$; df = 5,30; $P = 0.70$. All Bees: $F = 30.18$; df = 5,30; $P < 0.01$.

Table 18. Captures of *Popillia japonica* and bees in various color Japanese beetle traps baited with Trécé dual lures, 18 June – 17 August 2018, McMinnville, TN.

		$\bar{X} \pm$ SEM[a]				
Trap type	Lure	*P. japonica*	*Bombus* spp.	*X. virginica*	Other Apidae	Andrenidae
Clear	Dual	933.2 ± 112.2	13.8 ± 2.1a	0.3 ± 0.2	1.7 ± 0.4a	0.0 ± 0.0
Yellow top and green cage	Dual	1,326.7 ± 116.9	10.8 ± 3.4a	1.3 ± 1.0	1.5 ± 0.8a	0.0 ± 0.0
Red	Dual	1,036.7 ± 74.9	1.3 ± 0.3b	0.3 ± 0.3	0.2 ± 0.2b	0.0 ± 0.0
Black	Dual	1,008.0 ± 85.8	0.8 ± 0.3b	0.0 ± 0.0	0.0 ± 0.0b	0.0 ± 0.0
Brown	Dual	955.2 ± 74.2	1.7 ± 0.7b	0.2 ± 0.2	0.0 ± 0.0b	0.0 ± 0.0
Green	Dual	1,131.2 ± 117.7	3.2 ± 1.4b	0.0 ± 0.0	0.2 ± 0.2b	0.0 ± 0.0

Table 18. (continued).

Trap type	Lure	$\bar{X} \pm$ SEM[a] Halictidae	Megachilidae	All Bees	Total No. Bees Captured
Clear	Dual	3.2 ± 0.7a	0.3 ± 0.2	19.3 ± 2.4a	116
Yellow top and green cage	Dual	1.2 ± 0.5b	0.2 ± 0.2	15.0 ± 5.4a	90
Red	Dual	0.0 ± 0.0c	0.0 ± 0.0	1.8 ± 0.5b	11
Black	Dual	0.2 ± 0.2bc	0.2 ± 0.2	1.2 ± 0.3b	7
Brown	Dual	0.0 ± 0.0c	0.0 ± 0.0	1.8 ± 0.7b	11
Green	Dual	0.5 ± 0.2bc	0.0 ± 0.0	3.8 ± 1.2b	23

Table 18. (continued).

[a]Means in the same column followed by the same letters are not significantly different, $\alpha = 0.05$, LSD test, *Popillia japonica*: $F = 2.07$; df = 5,30; $P = 0.10$. *Bombus*: $F = 10.31$; df = 5,30; $P < 0.01$. *Xylocopa virginica:* $F = 1.37$; df = 5,30; $P = 0.27$. Other Apidae: $F = 3.84$; df = 5,30; $P < 0.01$. Halictidae: $F = 11.225$; df = 5,30; $P < 0.01$. Megachilidae: $F = 1.11$; df = 5,30; $P = 0.38$. All Bees: $F = 9.94$; df = 5,30; $P < 0.01$.

Fig. 1. PHEROCON Japanese beetle standard yellow trap top with 473 ml glass jar.

Fig. 2. PHEROCON Japanese beetle standard trap (yellow top and green cage).

Fig. 3. PHEROCON Japanese beetle trap (green top and green cage).

Fig. 4. PHEROCON Japanese beetle standard trap (yellow top and green cage) with a clear acetate shield.

Fig. 5. Clear plexiglass vanes and translucent funnel and clear plastic cage trap.

Fig. 6. Yellow bee vane trap.

Fig. 7. Clear plexiglass vanes and glass funnel and clear plastic cage trap

Fig. 8. Japanese beetle trap (red top and red cage).

Fig. 9. Japanese beetle trap (black top and black cage).

Fig. 10. Japanese beetle trap (brown top and brown cage).

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